Basic Science

# MRI-based morphological evidence of spinal cord tethering predicts curve progression in adolescent idiopathic scoliosis

Min Deng, MMed[a], Steve C.N. Hui, MSc[a], Fiona W.P. Yu, MSc[b], Tsz-Ping Lam, MBBS[b,c], Yong Qiu, MD[c,d], Bobby K.W. Ng, MBBS[b], Jack C.Y. Cheng, MBBS, MD[b,c], Winnie C.W. Chu, MBChB, MD[a,*]

[a]Department of Imaging and Interventional Radiology, Chinese University of HongKong, Pince of Wales Hospital, 30-32 Ngan Shing Street, Shatin, New Territories, Hong Kong, China
[b]Department of Orthopaedics and Traumatology, Chinese University of HongKong, Pince of Wales Hospital, 30-32 Ngan Shing Street, Shatin, New Territories, Hong Kong, China
[c]Joint Scoliosis Research Center of the Chinese University of HongKong, Pince of Wales Hospital, 30-32 Ngan Shing Street, Shatin, New Territories, Hong Kong, China
[d]Department of Spine Surgery, The Affiliated Drum Tower Hospital of Nanjing University Medical School, Zhongshan Road 321, Nanjing, China

**Abstract**

**BACKGROUND CONTEXT:** Existing prognostic factors for adolescent idiopathic scoliosis (AIS) patients have focused mainly on curve, maturity, and bone-related factors. Previous studies have shown significant associations between curve severity and morphological evidences of relative shorter spinal cord tethering in AIS, and increased prevalence of abnormal somatosensory cortical–evoked potentials and low-lying cerebellar tonsil in severe AIS. Earlier evidence suggests that there might be neural morphological predictors for curve progression.

**PURPOSE:** The purpose of this study was to identify any morphological predictors associated with cord tethering, as measured by magnetic resonance imaging (MRI), for curve progression in AIS patients.

**STUDY DESIGN/SETTING:** This is a prospective cohort study.

**PATIENT SAMPLE:** A total of 81 female AIS subjects between 10 and 14 years were included, without surgical intervention during the follow-up period.

**OUTCOME MEASURES:** Magnetic resonance imaging scans of hindbrain and whole spine and areal bone mineral density (BMD) at bilateral femoral necks were performed.

**METHODS:** All AIS patients were longitudinally followed up starting from initiation of bracing beyond skeletal maturity in 6-month intervals. Clinical and radiographic data were recorded at each clinic visit. Bone mineral density and MRI measurements including ratio of spinal cord to vertebral column length, ratio of anteroposterior (AP) and transverse (TS) diameter of cord, lateral cord space (LCS) ratio, cerebellar tonsil level, and conus medullaris position were obtained at baseline. Only compliant patients with a minimum 2-year follow-up were analyzed. Adolescent idiopathic scoliosis girls were assigned into three groups according to bracing outcome: Group A, nonprogression (curvature increase of less than or equal to 5°); Group B, progression (curvature increase of greater than or equal to 6°); Group C, progression with surgery indication (Cobb angle of greater than or equal to 50° after skeletal maturity despite bracing). The predictors for curve progression were evaluated using univariate analysis and multivariate ordinal regression model.

**RESULTS:** The average duration of follow-up was 3.4 (range, 2.0–5.6) years. There were 46 girls (57%) in Group A, 19 (23%) in Group B, and 16 (20%) in Group C. No significant intergroup differences were found in spinal cord length, tonsil level, and conus position. Group C had significantly longer vertebral column length, smaller cord-vertebral length ratio, and higher AP/TS cord ratio compared with Group A, whereas LCS ratio in Group C was significantly increased

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* Corresponding author. Department of Imaging and Interventional Radiology, Chinese University of HongKong, Pince of Wales Hospital, 30-32 Ngan Shing Street, Shatin, New Territories, Hong Kong, China. Tel.: 852-26322299; fax: 852-26360012.

*E-mail address:* winniechu@cuhk.edu.hk (W.C.W. Chu)

compared with both Group A and Group B. In regression model, five significant independent predictors including cord-vertebral length ratio (odds ratio [OR]: 1.993 [95% confidence interval {CI}: 1.053–3.771], p=.034), LCS ratio (OR: 2.639 [95% CI: 1.128–6.174], p=.025), initial Cobb angle (OR: 1.156 [95% CI: 1.043–1.281], p=.006), menarche age (OR: 1.688 [95% CI: 1.010–2.823], p=.046), and BMD (OR: 2.960 [95% CI: 1.301–6.731], p=.010) and a marginally significant predictor namely AP/TS cord ratio (OR: 1.463 [95% CI: 0.791–2.706], p=.096) were obtained.

**CONCLUSIONS:** On baseline MRI measurement, cord-vertebral length ratio and LCS ratio are identified as new significant independent predictors for curve progression in AIS, whereas AP/TS cord ratio is suggested as a potential predictor requiring further validations. The earlier MRI parameters can be taken into accounts for prognostication of bracing outcome.    © 2015 Elsevier Inc. All rights reserved.

## Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional structural deformity of the spine that occurs in otherwise healthy children, predominantly in adolescent girls, which typically progresses during the adolescent growth spurts, affecting 2% to 3% of children worldwide [1,2]. Despite decades of dedicated research, the etiopathogenesis of this classic orthopedic disorder remains uncertain. Scoliosis curves may remain static, progress slowly, or rapidly, whereas the prognostic factors governing curve progression are not totally clear. Severe scoliosis is associated with significant morbidities and disfiguration of body image. It is a major challenge to estimate the likelihood of curve deterioration so that proper treatment planning and counseling to the patients and the parents can be provided. Bracing has been widely applied in AIS patients aiming for preventing curve progression so that corrective surgery can be avoided [3–6]. Despite the previous controversies of bracing effectiveness [7–10], recent researches including a latest multicenter large-scale study have shown that bracing is superior to observation in clinical outcome [5,11,12]. Predictors for curve progression should be redefined for AIS patients with bracing treatment, rather than following predictors deriving from natural progression of curve in patients with observation.

Existing known predictors for curve progression despite bracing treatment in AIS are mainly focused on clinical factors such as chronologic age [13], Risser sign [14], menarchal status [13,15], and radiographic factors such as curve magnitude [13,15], curve pattern [16,17], and bone mineral density (BMD) [16,18]. Recently, calcaneal stiffness index detected by quantitative ultrasound has been determined as a new predictor [13].

Magnetic resonance imaging (MRI) is an excellent imaging modality for morphological delineation of soft-tissue and neural structures. It is now adopted in the protocol of preoperative planning in many centers. Research articles reporting abnormalities in the neuroaxis have renewed interest in abnormal neuroanatomy associated with AIS. Previous cross-sectional studies have revealed significant correlations between curve severity and morphological evidences of subclinical tethering of relative shorter spinal cord in AIS, such as reduced spinal cord to anterior vertebral column length ratio and altered cross-sectional shape of spinal cord [19,20]. In conjunction with increased prevalence of abnormal somatosensory cortical–evoked potentials and low-lying cerebellar tonsil in severe AIS compared with mild-to-moderate AIS [19,21], neuro-related factors might have predictive value for curve progression.

To the best of our knowledge, there is no longitudinal MR study evaluating the relationship between morphological evidences of relative shorter cord tethering with the progression of scoliosis curve. We sought to identify any new neural morphological predictors, as measured by MRI, to determine curve progression in brace-treated AIS patients.

## Materials and methods

### Subjects

During the period from July 2007 to April 2011, AIS subjects were prospectively recruited from our scoliosis clinics, which was one of the only two tertiary referral centers specialized in scoliosis, serving a population of seven million citizens. All subjects should be girls with right-sided thoracic/thoracolumbar curves with apical vertebra ranged from T6 to T12. All recruited subjects have been offered bracing according to the following Scoliosis Research Society modified inclusion criteria: age 10–14 years old, skeletal immaturity (Risser sign, 0–2), primary curve Cobb angle of 20° to 40°, no previous treatment, and either premenarchal or less than 1 year postmenarchal. Exclusion criteria included conditions and medications that would affect bone remodeling, calcium metabolism, neuromuscular abnormalities, genetic diseases, chromosomal defects, autoimmune disorders, and endocrine disturbances. Ethical approval was obtained from the University and Hospital Research Ethics Committee. All subjects provided written informed consent.

### Clinical assessment

Before bracing started, menarche status was recorded. Body weight, standing height, sitting height, and arm span